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DOI:
10.1016/j.compedu.2010.07.016

Document status and date:
Published: 01/12/2010

Document Version:
Peer reviewed version

Fostering Complex Learning-task Performance through Scripting Student Use of Computer Supported Representational Tools

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Abstract

This study investigated whether scripting student use of computer supported representational tools fostered students' collaborative performance of a complex business-economics problem. Scripting the problem-solving process sequenced and made its phase-related part-task demands explicit, namely (1) determining core concepts, (2) proposing multiple solutions, and (3) coming to a final solution. The representational tools facilitated students in constructing specific representations of the domain (i.e., conceptual, causal, or mathematical) and were each suited for carrying out the part-task demands of a specific phase. Student groups in four experimental conditions had to carry out all part-tasks in a predefined order, but differed in the representational tool(s) they received during their collaborative problem-solving process. In three mismatch conditions, student groups received either a conceptual, causal, or simulation representational tool which supported them in only carrying out one of the three part-tasks. In the match condition, student groups received the three representational tools in the specified order, each matching the part-task demands of a specific problem phase. The results revealed that student groups in the match condition constructed more task-appropriate representations and had more elaborated and meaningful discussions about the domain. As a consequence, those student groups performed better on the complex learning-task. However, similar results were obtained by student groups who only received a representational tool for constructing causal representations for all part-tasks.

Keywords: Complex Learning-tasks, Computer Supported Collaborative Learning-environments, External Representations, Pedagogical Issues, Secondary Education

1. Introduction

There has been a recent surge in the interest of educational researchers for studying the effects of computer supported tools for fostering students' complex learning-task performance (Demetriadis, Papadopoulos, Stamelos, & Fischer, 2008; Slof, Erkens, Kirschner, Jaspers, & Janssen, 2010; Zydney, 2010). Carrying out complex learning-tasks requires students to actively engage in a dynamic process of sense-making (Kirschner, Buckingham Shum, & Carr, 2003) by articulating and discussing multiple representations on the problem and their problem-solving strategy. Through externalizing one's knowledge, discussing this with peers, and establishing and refining the group's shared understanding of the domain, students often acquire new knowledge and skills and process them more deeply (Ding, 2009; Hmelo-Silver, Duncan, & Chinn, 2007; Kirschner, Beers, Boshuizen, & Gijselaers, 2008). Educators and instructional designers, however, should realize that students (e.g., novices) need ample instructional support to make their problem-solving process more efficient and effective (Kirschner, Sweller, & Clark, 2006). Students tend to focus on superficial details of problems instead of focusing on the underlying principles of the domain (Corbalan, Kester, & Van Merriënboer, 2009), and to employ weak problem-solving strategies such as working via a means-ends strategy towards a solution (Simon, Langley, & Bradshaw, 1981; Van Merriënboer & Kirschner, 2007). To this end, it would be beneficial to support students in acquiring different problem representations of the domain in which they are working and in using those representations to solve the given problem (Frederiksen & White, 2002; Jonassen, 2003; Ploetzner, Fehse, Kneser, & Spada, 1999).

Research on Computer Supported Collaborative Learning (CSCL) has shown that collaboratively constructing and discussing domain-specific representations beneficially affects complex learning-task performance (Fischer, Bruhn, Gräsel, & Mandl, 2002; Lazakidou & Retalis, 2010; Wegerif, McClaren, Chamrada, Schreuer, Mansour, Mikšátko et al., 2010). Embedding representational tools in a CSCL-environment can facilitate students' construction of different representations of the domain and, thereby, guide their interaction and, thus, their collaborative problem-solving process. A tool's ontology (i.e., objects, relations, rules for combining objects and relations) provides a specific kind of representational guidance which makes certain concepts and/or relationships (e.g., causal, mathematical) salient in favor of others. In this way, a tool's representational guidance supports externalization of knowledge and ideas about specific aspects of a domain (Ertl, Kopp, & Mandl, 2008; Suthers, 2006; Van Bruggen, Boshuizen, & Kirschner, 2003). This may foster students' understanding because it stimulates cognitive processes such as selecting relevant information, organizing information into coherent structures, and relating it to prior understanding (Liu, Chen, & Chang, 2010; Shaw, 2010; Stull & Mayer, 2007). Collaborative learning, due to its emphasis on dialogue and discussion, can stimulate the elaboration of these representations so that multiple perspectives on the domain and of the problem-solving strategy can arise (De Simone, Schmid, & McEwan, 2001; Hmelo-Silver et al., 2007). When students are able to create a shared understanding of these different viewpoints and negotiate about them, this fosters their performance of complex learning-tasks (Ding, 2009; Erkens, Jaspers, Prangsma, & Kanselaar, 2005; Mercer, Littleton, & Wegerif, 2004). Although the educational benefits of representational tools are widely recognized, some studies report mixed or even negative findings and, thus, question how student interaction can best be guided (Bera & Liu, 2006; Elen, & Clarebout, 2007; Van Drie, Van Boxtel, Jaspers, & Kanselaar, 2005). This inconsistency in the literature hinders educators and instructional designers in designing representational tools that foster students' performance of complex learning-tasks.

1.1 Designing representational tools to foster complex learning-task performance

1.1.1 Drawbacks

Since representational tools guide students in constructing and, thus, discussing specific representations of the domain, educators and instructional designers should realize that such tools are only appropriate for carrying out specific task demands (Ainsworth, 2006; Bodemer & Faust, 2006; Schnotz & Kürschner, 2008). The mere presence or availability of a representational tool does not, therefore, automatically support students in solving complex problems. Important here is that those problems are usually composed of fundamentally different phase-related part-tasks demands (e.g., Van Bruggen et al., 2003), namely:

- Problem orientation; determining core concepts and relating them to the problem,
- Problem solution; proposing solutions to the problem,
- Solution evaluation; determining suitability of the solutions and coming to a final solution to the problem.

Each problem phase requires a different representation on the domain and, thus, requires a representational tool with a specific kind of representational guidance. When the design of the tool is incongruent with the demands of one or more phase-related part-tasks this should negatively affect the student's performance of a complex learning-task (Slof et al., 2010; Suthers, 2006; Van Bruggen et al., 2003). Here, students cannot properly make sense of the domain and are, thus, hindered in acquiring and applying their understanding of the domain.

To evoke elaborate and meaningful discussions about the domain requires a representational tool that (1) is in line with its users' capabilities and intentions, and (2) makes clear what its users can and should do with it (Kirschner, Martens, & Strijbos, 2004; Veldhuis-Diermanse, 2002). If this is not the case, then students might experience at least two difficulties when using them. First*, part-task related difficulties* may arise when students do not have a realistic idea of the concepts and relationships they must use and how they should relate them to the problem. Due to this, students experience difficulties in constructing and interpreting their representations and, thus, in acquiring a well-developed understanding of the domain (Bodemer & Faust, 2006; Brna, Cox, & Good, 2001; Liu et al., 2010). Furthermore, students might see constructing the representation as an additional task-demand instead of as support. When this is the case, after the concepts are interrelated in the representation, students pay no further attention to the representation and, therefore, do not apply it to complete their learning-task (De Simone et al., 2001; Suthers, Hundhausen, & Girardeau, 2003). Second, students in CSCL-environments often make use of multiple tools (e.g., chat tools, representational tools) in a non-sequential way which makes keeping track of each others' knowledge, ideas, and actions rather complicated. When students are unable to properly interpret the conveyed messages and relate them to each other, they experience *communicative difficulties* (Andriessen, Baker, Suthers, 2003; Barron, 2003; Erkens et al., 2005). Such difficulties often hinder students in elaborating on and meaningfully discussing the content of the domain. Whether students are able to have such discussions depends on how easily they can refer to and relate their contributions with those of others (i.e., deictic referencing, see Reinhard, Hesse, Hron, & Picard, 1997; Suthers et al., 2003; Van Boxtel & Veerman, 2001). Important here is that the provided computer tools support students in coordinating their collaboration process by carrying out communicative activities. That is, students have to make their own knowledge and ideas explicit to other group members. When made explicit, students must try to maintain a shared topic of discourse (i.e., achieve a common *focus*) and repair that focus if they notice focus divergence. Understanding and relating the relevance of individual messages may be hard when students are simultaneously discussing different topics. Student should, therefore, coordinate their topic of discourse by focusing (Erkens & Janssen, 2008; Van Drie et al., 2005). Since not all concepts, principles, and procedures are relevant for carrying out a specific part-task students also must maintain the coherence and consistency of their shared understanding by *checking* (Van der Linden, Erkens, Schmidt, & Renshaw, 2000). Furthermore, students must come to an agreement about relevant concepts, principles and procedures. Through *argumentation* they can try to change their partners' viewpoint to arrive at the best way to carry out a part-task or at a definition of concepts acceptable for all. In this argumentation process they try to convince the other/others by elaborating on their own point of view, and by explaining, justifying and accounting (Andriessen et al., 2003; Kirschner et al, 2008).

1.1.2 Scripting

Just providing a user/student a tool does not guarantee use or proper use of that tool. To this end, students must understand what they can and should do with the tool and how its use is integrated within learning-task at hand (Kirschner et al., 2004; Veldhuis-Diermanse, 2002). *Scripting* has been advanced as a technique to ensure proper alignment between the design of the representational tool, student tool use, and the required task demands (Dillenbourg, 2002; Weinberger, Ertl, Fischer, & Mandl, 2005). According to Dillenbourg a script is "a set of instructions regarding to how the group members should interact, how they should collaborate and how they should solve the problem" (p. 64). In our study students worked collaboratively on a case-based business-economics problem in which they had to advise an entrepreneur about changing the business strategy to increase profits (i.e., company result). Scripting was employed here to tailor the congruency of the representational guidance to the phase-related part-task demands of this complex learning-task. Integrating scripting with the availability of representational tools sequences and makes the different part-task demands explicit which should guide students in carrying out appropriate part-task related activities. That is, students may be evoked to carry out *cognitive activities* such as (1) discussing the goal of the problem-solving task/part-tasks, (2) discussing and selecting concepts, principles, and procedures in the domain, and (3) formulating and revising their decisions (Janssen, 2008; Jonassen, 2003). Students may also be induced to employ a proper problem-solving strategy and reflect on its suitability through carrying out *meta-cognitive activities* (Lazonder & Rouet, 2008; Narciss, Proske, & Koerndle, 2007). This requires that students discuss (1) how they should approach the problem (i.e., plan), (2) whether they have finished the part-tasks on time (i.e., monitor), and (3) how suitable their approach was (i.e., evaluate/reflect). Carrying out such cognitive and meta-cognitive activities should enable students to properly discuss both the content of the domain and their problem-solving strategy, fostering their performance of the complex learning-task (Hmelo-Silver et al., 2007; Ploetzner et al., 1999).

1.1.3 Matching the tools' representational guidance to the phase-related part-tasks

To gain insight into the phase-related part-tasks and their required domain-specific representations, a learning-task analysis (Anderson & Krathwohl, 2001; Gagné, Briggs, & Wagner, 1992) was conducted. Based on these insights, the sequence and the demands of the part-tasks were specified and part-task congruent representational tools were developed (see Table 1).

**** PLEASE INSERT TABLE 1 ABOUT HERE ****

In the *problem orientation phase* students have to explain what they think the problem is and describe what the most important factors are for solving it. Student interaction should, therefore, be guided towards selecting the core concepts needed to carry out this part-task and discussing how those concepts are qualitatively related to each other. The design of the representational tool should facilitate students in constructing and discussing a global qualitative problem representation by guiding and supporting them in conceptually relating the relevant concepts. Figure 1 shows an expert model of the concepts and their conceptual interrelationships involved in this study. The conceptual representational tool facilitates representation of the concepts and their interrelationships shown in Figure 1. Selecting and relating concepts that the students may regard as beneficial for solving the problem supports them in becoming more familiar with those concepts and in broadening their problem space. Students receiving the conceptual tool could, for example, make explicit that the 'company result' is related to the 'total profit' and 'efficiency result'. This should guide those students in elaborating (i.e., causal, mathematical) on the relationships in the two following problem phases, making it easier for them to find multiple solutions to the problem and to evaluate their effects.

**** PLEASE INSERT FIGURE 1 ABOUT HERE ****

In the *problem solution phase* students have to formulate several solutions to the problem and make clear how these interventions affect the outcomes (i.e., a company's results). Student interaction should, thus, be guided towards formulating multiple solutions and discussing how each of these solutions affects the selected core concepts by further specifying the relationships between the concepts and the proposed interventions. The representational tool should facilitate construction and discussion of a causal problem representation by causally relating concepts to each other and to possible interventions. Figure 2 shows an expert model of the concepts, the possible interventions and their causal interrelationships involved in this study. The causal representational tool facilitates representation of the concepts, interventions and their interrelationships shown in Figure 2. Selecting relevant concepts and interventions and causally relating them supports the effective exploration of the solution space and, thus, of finding multiple solutions to the problem. Students receiving the causal representational tool could, for example, make explicit that an intervention such as a employing a promotion-campaign (e.g., placing an advertisement in a paper) affects 'actual sales', which in turn affects ‘total profit’. Only conceptually representing the interrelationships of the concepts, as in the first problem phase, is not expressive enough for this part-task since the relationships need to be further specified and students need additional information about the possible solutions. If this is not the case, then students are forced to come up with a solution (i.e., the advice) themselves without sufficient understanding of the underlying qualitative principles governing the domain.

**** PLEASE INSERT FIGURE 2 ABOUT HERE ****

Finally, in the *solution evaluation phase* students have to determine the financial consequences of their proposed interventions and formulate a final advice for the entrepreneur by discussing the suitability of the different interventions with each other. Student interaction should, therefore, be guided towards determining and comparing the financial consequences by discussing the mathematical relationships between the selected concepts. The representational tool must, thus, facilitate constructing and discussing a quantitative representation by specifying the relationships as equations. Figure 3 shows an expert model of the concepts and their mathematical interrelationships involved in this study. The simulation representational tool facilitates representation of the concepts and their interrelationships shown in Figure 3. Selecting relevant concepts and specifying the interrelationships as equations supports students in evaluating the effects of their proposed interventions and, thus, in coming to a suitable advice. Students receiving the simulation representational tool could, for example, simulate how an intervention such as employing a promotion-campaign affects the ‘actual sales’ and whether this affects the ‘total profit. By entering values and adjusting them (i.e., increasing or decreasing), the values of the other related concepts are automatically computed. Since such quantitative representations can only be properly understood and applied when students have well-developed qualitative understanding of the domain, this kind of support is only appropriate for carrying out this type of part-task.

**** PLEASE INSERT FIGURE 3 ABOUT HERE ****

1.2 Purpose, design and hypotheses

The research reported on here was aimed at determining whether and how scripting the use of representational tools affects the performance of complex learning-tasks in CSCL. To study the effects of the representational scripting, four experimental conditions were defined by either matching or mismatching the tools’ representational guidance to the part-task demands (see Table 2).

**** PLEASE INSERT TABLE 2 ABOUT HERE ****

Scripting the problem-solving process sequenced and made its phase-related part-task demands explicit, these part-task are (1) determining core concepts, (2) proposing multiple solutions, and (3) coming to a final solution (see Section 1.1.3). Student groups in four experimental conditions had to carry out all part-tasks in a predefined order, but differed in the representational tool(s) they received during their collaborative problem-solving process. In three mismatch conditions, students only received one of the representational tools (i.e., conceptual, causal, or simulation tool) for constructing the part-task related representations and carrying out all three part-tasks. The tools' representational guidance matched only one of the part-tasks and there was a mismatch for the other two. Those student groups were, thus, only supported in carrying out one of the part-tasks. In the fourth, match, condition, student groups received all three representational tools in a phased order, receiving the tool considered to be most suited to the part-task demands of each problem phase. Due to this presumed match between tools' representational guidance and the part-tasks, it was hypothesized that student groups in the match condition would:

(H1) construct representations that are more suited for carrying out the part-tasks;

(H2) have more elaborate and meaningful discussions, evidenced by carrying out more:

a) part-task related activities such as cognitive and meta-cognitive activities,

b) communicative activities to coordinate their part-related activities; and

(H3) arrive at better problem solutions.

2. Method

2.1 Participants

Participants were students from six business-economics classes in three secondary education schools in the Netherlands. The total sample consisted of 93 students (60 male, 33 female). The mean age of the students was 16.74 years (SD = .77, Min = 15, Max = 18). The students were, within classes, randomly assigned to a total of 31 triads; seven triads in the match condition and eight triads in each of the three mismatch conditions. The administration and analysis of a pre-test to determine students' prior understanding of the domain did not reveal any significant differences between conditions and classes.

2.2 CSCL-environment

Students worked in a CSCL-environment called Virtual Collaborative Research Institute (VCRI, see Figure 4), a groupware application for supporting the collaborative performance of problem-solving tasks and research projects (see Erkens et al., 2005). For this study, the tools that are part of the VCRI were augmented with representational scripting. In the

Assignment menu, students can find the description of the problem-solving task/part-tasks. Besides this, additional information sources such as a definition list, formula list, and clues for solving the problem were also available here. The *Model menu* enabled students in constructing and adjusting their representations by either adding or deleting relationships. At the start of the first lesson all diagram boxes – representing the different concepts – were placed on the left side of the *Representational tool* so students could select them when they wanted to add a new relationship. The *Chat tool* enabled synchronous communication and supported students in externalizing and discussing their knowledge and ideas. The chat history is automatically stored and can be re-read by the students. The *Notes tool* is an individual notepad that allowed students to store information and structure their own knowledge and ideas before making them explicit. The *Co-writer* is a shared text-processor where students could collaboratively formulate and revise their decisions. The *Status bar* is an awareness tool that displayed which group members were logged into the system and which tool a group member used at a specific moment.

The different conditions were information equivalent and only differed in the way that the representational tools were intended to guide student interaction and their complex learning-task performance.

**** PLEASE INSERT FIGURE 4 ABOUT HERE ****

2.3 Scripting student tool use

All student groups were coerced to carry out the part-tasks in a predefined order (i.e., used the same script) and could, thus, only start with a new part-task after finishing an earlier part-task. When group members agreed that a part-task was completed, they had to 'close' that phase in the assignment menu. This 'opened' a new phase, which had two consequences for all students, namely they were instructed to (1) carry out a new part-task and (2) revise their representation of the domain so it concurred with the answers they gave to the new part-task. Students in the mismatch conditions were facilitated in elaborating on their previously constructed representation. Since those students kept the same representational tool, all concepts and their relationships remained visible and could be revised as students seemed appropriate for carrying out their new part-task. Students in the match condition were facilitated in acquiring and applying a different qualitative or quantitative perspective of the domain. That is, the previously selected concepts remained visible and students were instructed to replace the relationships by specifying them in a causal manner or as equations with the aid of their new representational tool.

2.4 Procedure

All student groups spent six, 45-minute lessons solving the problem during which each student worked on a separate computer. Before the first lesson, students received an instruction about the CSCL-environment, the complex learning-task, and the group composition. The instruction made it clear that their score on the complex learning-task would serve as a grade affecting their GPA. Students worked on the problem in the computer classroom where all actions and decisions were logged. During the lessons, the teacher was on stand-by for task related questions and a researcher was present for technical support.

2.5 Measurement

To gain insight in whether and how scripting student tool use affects their complex learning-task performance in CSCL, data concerning students' learning process (i.e., quality of the constructed representations and student interaction) as well as their learning results (i.e., complex learning-task performance) were collected.

2.5.1 Quality of the constructed representations

To examine the effect of condition on the quality of the constructed representations, a content analysis was conducted on all three phase-related representations. The representations were selected at the end of each problem phase, just before students 'closed' their part-task (see Section 2.3), and transferred from the log-files using the Multiple Episode Protocol Analysis (MEPA) program (Erkens, 2005). Then they were coded with respect to how many concepts and relationships were represented and whether they were represented correctly. It should be noted that the (nine) possible interventions were also coded as concepts since students receiving the causal tool were facilitated in representing them. When a concept was related to multiple other concepts, it received a code for each relationship and could, thus, be coded several times. The coding was done automatically with a MEPA-filter which makes use of 364 'if-then' decision rules containing explicit references to the concepts, the relationships and its correctness (based on the expert models, see Figures 1-3).

2.5.2 Student interaction

The chat-protocols were selected and transferred from the log-files using the MEPA program. The content of these chat-protocols is assumed to represent what students know and consider important for carrying out their problem-solving task (Chi, 1997; Moos & Azevedo, 2008). Using so called 'concordancers' software (e.g., MEPA, Erkens; !Kwictex, Mercer et al., 2004) minimizes the work associated with coding the chat-protocols and maximizes coding allowing the content of chat-protocols to be searched for the occurrence of important words or phrases within their linguistic context to show their specific function in the dialogue.

To examine the effect of condition on students' *part-task related activities*, two coding schemes were applied. Measurement of students' discourse topics provided insight into the *cognitive, meta-cognitive and off-task activities* carried out (see Table 3). The topics were hand-coded and Cohen's kappa was computed for three independently coded chat-protocols (3,532 lines) by two coders. An overall Cohen's Kappa of .70 was found, an intermediate to good result (Cicchetti, Lee, Fontana, & Dowds, 1978). Measurement of students' interaction about the concepts, interventions and the ways of interrelating them provided insight into their discussion of the *content of the domain* (see Table 4). A problem here is that even within in a single sentence, multiple concepts or statements may be expressed and thus require multiple codes (Erkens & Janssen, 2008; Strijbos, Martens, Prins, & Jochems, 2006). With a MEPA-filter which makes use of 300 'if-then' decision rules, the utterances were automatically segmented into smaller, still meaningful, subunits. Punctuation marks (e.g., full stop, exclamation mark, question mark, comma) and connecting phrases (e.g., 'and if', or 'but if') were used to segment the utterances. After segmentation, the coding was done automatically with a MEPA-filter which makes use of 900 'if-then' decision rules containing explicit references to a concept, solution or relationship (e.g., name, synonyms, etc.) which were coded as representing that concept, solution or relationship. Overall Cohen's Kappa for concepts, solutions and relationships ranging from .68 to .83, were reached compared to hand-coding three chat-protocols (3,020 lines).

****PLEASE INSERT TABLE 3 ABOUT HERE****

****PLEASE INSERT TABLE 4 ABOUT HERE****

To examine the effect of the condition on students' *communicative activities* each utterance was coded with respect to the type of dialogue act used (see Table 5). A dialogue act is regarded as a communicative action which is elicited for a specific purpose representing a specific function in the dialogue (Erkens et al., 2005; Mercer et al., 2004). The coding was based on the occurrence of characteristic words or phrases (i.e., discourse markers; see Schiffrin, 1987) which indicate the communicative function of an utterance (see Table 5). This was done automatically with a MEPA-filter using 1,250 'if-then' decision rules that uses pattern matching to find typical words or phrases. When compared to hand-coding, an overall agreement of 79% was reached and a Cohen's Kappa of .75 was found (Erkens & Janssen, 2008).

**** PLEASE INSERT TABLE 5 ABOUT HERE****

2.5.3 Complex learning-task performance

To examine the effect of the condition on complex learning-task performance, an assessment form for all three part-task and the quality of the final advice was developed. Table 6 provides a description of the aspects on which the decisions were evaluated, the number of items, and their internal consistency scores (i.e., Cronbach's alpha). The 41 items could all be coded as '0' (wrong), '1' (adequate) or '2' (good); the higher the code, the higher the quality of the decision. Groups could, thus, achieve a maximum score of 82 points for their learning-task performance (41 items × 2 points) and a minimum of 0 points. The internal consistency score for the whole complex learning-task performance was .92 and for most subscales, internal consistency scores of .56 or above were obtained.

****PLEASE INSERT TABLE 6 ABOUT HERE****

2.6 Analyses

2.6.1 Quality of the constructed representations

Content analyses were conducted to examine the effect of condition on the quality of the constructed representations. To this end, students' part-task related representations of the concepts, their relationships and the correctness of those relationships were analyzed.

2.6.2 Student interaction

Multilevel analyses (MLAs) were used to examine the effects of condition on student interaction. This technique is suited to address the statistical problem of non-independence that is often associated with conducting studies on CSCL (Cress, 2008; Janssen, 2008; Strijbos & Fischer, 2007). Many statistical techniques (e.g., *t*-test, ANOVA) assume score-independence and a violation of this assumption compromises the interpretation of the output of their analyses (e.g., *t*-value, standard error, *p*-value, see Kenny, Kashy, & Cook, 2006). The non-independence was determined here by computing the intraclass correlation coefficient and its significance (Kenny et al.) for all dependent variables concerning student interaction. This coefficient demonstrated non-independence ($\alpha < .05$) for all tests, justifying MLA for analyzing these data. MLA entails comparing the deviance of an empty model and a model with one or more predictor variable(s) to compute a possible decrease in deviance. The latter model is considered a better model when there is a significant decrease in deviance in comparison to the empty model (tested with a χ^2-test). Almost all reported χ^2-values were significant ($\alpha < .05$) and, therefore, the estimated parameters of these predictor variables (i.e., effects of condition) were tested for significance.

2.6.3 Complex learning-task performance

A one-way MANOVA was used to examine the effect of condition on complex learning-task performance. There was no need to use MLAs because the complex learning-task performance was measured at the group level instead of the student level. Since there were specific directions of the results expected (see Section 1.2) all analyses are one-sided.

3. Results

3.1 Quality of the constructed representations

The content analyses (see Figure 5) revealed several differences concerning the quality of the constructed representations between conditions. First, students in the match condition represented fewer concepts and relationships than students in both the conceptual and the causal conditions. Second, students in both the conceptual condition and the simulation conditions represented the relationships more correctly than students in the causal condition. Third, students in the simulation condition represented fewer concepts and relationships than students in the other conditions, though they were more successful in correctly relating the concepts to each other.

****PLEASE INSERT FIGURE 5 ABOUT HERE****

Furthermore, several conditions effects were obtained when analyzing the part-task related representations in relation to the phase-related part-tasks. First, compared to students in both the conceptual and the causal conditions, students in the match condition represented fewer *concepts* and *relationships* within their second and third representation than they did in their first. Second, compared to students in both the conceptual and the simulation conditions, students in the causal condition and students in the match condition varied more in whether they correctly *represented the relationships*.

As expected, students in the match condition differed in representing the content of domain when carrying out the different part-tasks. After constructing a mostly correct global representation, students became more selective in representing the concepts and specifying their relationships in a causal or mathematical manner.

3.2 Student interaction

3.2.1 Cognitive, meta-cognitive and off-task activities

MLAs revealed that condition was not a predictor for students' meta-cognitive activities ($\beta = 1.74$, $p = .26$), cognitive activities ($\beta = 2.64$, $p = .20$), and off-task activities ($\beta = -.30$, $p = .42$). The mean scores, standard deviations and condition effects (i.e., difference between match condition and non-matched conditions) for the different kinds of discourse topics are listed in Table 7.

When analyzing the different discourse topics for the conditions separately, two condition effects were found. First, a significant category effect for *meta-cognitive activities* was found when comparing students in the match condition to students in the simulation condition ($\beta = 4.57$, $p = .04$). As indicated by the $^{+}$ and $^{-}$ signs in Table 7, students in the match condition exhibited more meta-cognitive activities compared to students in the simulation condition. Students in the simulation condition discussed whether they had finished their part-tasks on time (i.e., monitoring) less compared to students in the match condition ($\beta = 2.42$, $p = .03$). Second, a significant category effect for *cognitive activities* was found when comparing students in the match condition with students in the simulation condition ($\beta = 5.23$, $p = .04$). Students in the simulation condition discussed fewer content-related discourse topics and formulated/revised their decisions (i.e., content) less often compared to students in the match condition ($\beta = 3.82$, $p = .05$). Finally, students in the simulation condition discussed what the goal of the problem-solving task and the different part-tasks was (i.e., preparation) less than students in the match condition ($\beta = 0.72$, $p = .05$).

Contrary to our expectations, students in the match condition only carried out more meta-cognitive and more cognitive activities than students in the simulation condition. No significant differences were obtained for the comparison with students in both the conceptual and the causal conditions.

****PLEASE INSERT TABLE 7 ABOUT HERE****

3.2.2 Concepts, solutions and relations

MLAs revealed that condition was not a significant predictor for the number and kinds of concepts ($\beta = 2.41$, $p = .25$), solutions ($\beta = 1.27$, $p = .36$) and relations ($\beta = 1.73$, $p = .34$) discussed. The mean scores, standard deviations and condition effects (i.e., difference between match condition and non-matched conditions) for the discussion of concepts, solutions and relations are shown in Table 8.

When analyzing these variables for the conditions separately, two condition effects were found. First, a marginally significant category effect for *concepts* was found when comparing students in the match condition to students in the simulation condition ($\beta = 4.49$, $p = .07$). Second, a significant category effect for *relationships* was found; students in the match condition discussed more and more different kinds of relationships than students in the simulation condition ($\beta = 5.74$, $p = .05$). It appeared that this was (marginally) the case for the conceptual ($\beta = 1.54$, $p = .07$) and the causal relationships ($\beta = 3.85$, $p = .05$).

Contrary to our expectations, students in the match condition only had more elaborated discussions of the domain than students in the simulation condition. No significant differences were obtained for the comparison with students in both the conceptual and the causal conditions.

****PLEASE INSERT TABLE 8 ABOUT HERE****

3.2.3 Communicative activities

MLAs revealed that condition was a (marginally) significant predictor for the communicative activities students exhibited when comparing students in the match condition to students in both the conceptual ($\beta = 23.84$, $p = .06$) and the simulation conditions ($\beta = 42.00$, $p = .00$). The mean scores, standard deviations and condition effects (i.e., difference between match condition and non-matched conditions) for the communicative activities are listed in Table 9. When analyzing students' communicative activities for the conditions separately, several category effects were found. First, a significant category effect for *focusing* was found; students in the match condition were better able to coordinate what their topic of discourse was than students in both the conceptual ($\beta = 4.22$, $p = .05$) and the simulation conditions ($\beta = 6.68$, $p = .02$). Second, a significant category effect for *checking* was found; students in the match condition devoted more attention to guarding the coherence and consistency of their shared understanding of the domain than students in both the conceptual ($\beta = 14.08$, $p = .04$) and the simulation conditions ($\beta = 23.03$, $p = .00$). Finally, a significant category effect was found for *argumentation*; students in the match condition exhibited more argumentative activities than students in the simulation condition ($\beta = 12.17$, $p = .02$).
As expected, students in the match condition were better able to establish and maintain shared understanding of the domain than students in both the conceptual and simulation conditions. These differences were, however, not found for the comparison with students in the causal condition.

****PLEASE INSERT TABLE 9 ABOUT HERE****

3.3 Complex learning-task performance

A One-way MANOVA on the total score for problem-solving showed a significant difference for condition ($F(3,27) = 4.38$, $p = .01$). Bonferroni post hoc analyses revealed that student groups in the match condition scored significantly higher than student groups in both the conceptual ($p = .01$; $d = 1.46$) and the simulation conditions ($p = .01$; $d = 1.48$). When the results for the dependent variables were considered separately – using one-way ANOVAs with Bonferroni post hoc analyses – condition effects were found for 'justification' ($F(3,27) = 4.85$, $p = .01$) and 'correctness' ($F(3,27) = 3.97$, $p = .01$). The mean scores, standard deviations and condition effects (i.e., difference between match condition and non-matched conditions) for the complex learning-task performance are listed in Table 10. The mean scores indicate that there were two significant differences between conditions. First, groups in the match condition scored significantly higher on 'justification' than groups in both the conceptual ($p = .01$; $d = 1.56$) and simulation conditions ($p = .01$; $d = 1.56$). Second, groups in the match condition scored significantly higher on 'correctness' than groups in both the conceptual ($p = .01$; $d = 3.97$) and simulation conditions ($p = .03$; $d = 2.52$).

As expected, student groups receiving part-task congruent representational tools scored higher on complex learning-task performance. Although expected, no significant differences were obtained between student groups in the match condition and the causal condition.

****PLEASE INSERT TABLE 10 ABOUT HERE****

3.4 Anomalies

Since our hypotheses were focused on comparing the performance of student groups in the match condition to student groups in the mismatch conditions our analyses and results, thus far, have been reported accordingly. However, the means and standard deviations (see Tables 7-10) indicated that student interaction and complex learning-task performance of student groups in the causal condition and the match condition were quite similar. Student groups in both the causal and match conditions, in contrast to those in the other conditions, were facilitated to construct causal representations of the domain. This could have supported those groups in causal reasoning about the domain, a learning activity that is regarded as beneficial for learning (Jonassen & Ionas, 2008; McCrudden, Schraw, Lehman, & Poliquin, 2007). Guiding students' causal reasoning about the content of the domain might, thus, account for the differences in learning process (i.e., student interaction) and learning results (i.e., complex learning-task performance). Since these are noteworthy results, additional, two-sided analyses were carried out to determine whether the results obtained for student groups in the match condition also applied for student groups in the causal condition.

MLAs revealed that students in the causal condition also exhibited more part-task related and communicative activities than students in the simulation condition. Students in the causal condition (marginally) (1) exhibited more meta-cognitive activities ($\beta = 7.56$, $p = .04$) and off-task activities ($\beta = 2.09$, $p = .07$) and (2) discussed more and different kinds of relationships ($\beta = 7.78$, $p = .07$). Also, students in the causal condition were significantly better able to coordinate their part-task related activities ($\beta = 46.56$, $p = .05$). These results were obtained for all categories. A One-way MANOVA with Bonferroni post hoc analyses revealed that student groups in the causal condition marginally significantly outperformed student groups in both the conceptual ($p = .08$; $d = 1.14$) and the simulation conditions ($p = .08$; $d = 1.16$) on the complex learning-task performance.

These results indicate that the problem-solving process of student groups in the causal condition were also efficient and effective.

4. Discussion

Embedding representational tools in CSCL-environments is often regarded as beneficial for learning. Such tools can facilitate students' construction and discussion of different representations of the domain and, thereby, guiding their learning process and foster their learning-task performance (Fischer et al., 2002; Wegerif et al., 2010). Although its importance is widely recognized, there are, however, also studies that report mixed or negative effects on learning (Elen & Clarebout, 2007; Van Drie et al., 2005). An important reason for these contrasting findings seems that the complexity of the learning-task is not properly taken into account when designing representational tools. Since a representational tool is often suited for coping with the demands of a specific task, it hinders students in carrying out learning-tasks which consist of multiple part-tasks (Ainsworth, 2006; Van Bruggen et al., 2003).

The present study, therefore, examined whether and how embedding part-task congruent representational tools in a CSCL-environment fostered student collaborative problem-solving performance. Scripting the problem-solving process sequenced and made its phase-related part-task demands explicit, namely (1) determining core concepts, (2) proposing multiple solutions, and (3) coming to a final solution. By doing so, each problem phase could be foreseen with a part-task congruent representational tool. Scripting student use of representational tools was aimed at guiding their learning process (i.e., quality of the constructed representation and student interaction) and their learning results (i.e., complex learning-task performance). The results indicate that student groups who received the complete array of tools (i.e., match condition) were indeed stimulated in their complex learning-task performance. That is, those groups formulated better decisions with respect to the part-tasks and came up with better final solutions to the problem than students in both the conceptual and the simulation conditions. This difference in learning results might be explained by the differences concerning students' learning process. Students in the match condition started by constructing a broad representation and gradually became more selective in representing the concepts and specifying their relationships in a causal or mathematical manner. This is the way that solving such a problem should theoretically be carried out (e.g., Van Merriënboer & Kirschner, 2007). In contrast, students who only had access to one of the representational tools (i.e., conceptual, causal, or simulation) represented more or less the same concepts and relationships and were, thus, less occupied with fine-tuning their representations to the different part-task demands. Although the quality of the constructed representation differed for each part-task, almost no differences between the conditions concerning students' part-task related activities were obtained. Since student groups in all conditions had to construct a representation of the domain for each part-task, the learning activity in itself did no differ per condition. So perhaps students in all conditions were stimulated to discuss the content of the domain and their problem-solving strategy. This explanation seems consistent with the literature on CSCL which shows that the collaborative construction of external representations stimulates students' cognitive and meta-cognitive activities (e.g., De Simone et al., 2001). On the other hand, the lack of differences might also be due to the role of scripting. Structuring the problem-solving process into three phases, each focusing on one of the part-tasks, could have affected students' part-task related activities in the same manner (Dillenbourg, 2002; Kirschner et al., 2008). Whereas the discussion about the domain and the problem-solving strategy were very quite the same, students in the match condition exhibited more communicative activities than students in both the conceptual and simulation conditions. That is, they were better able to establish and maintain a shared understanding of the domain, which is regarded as a prerequisite for having a meaningful discussion of the domain (e.g., Van der Linden et al., 2000). It seems that the deictic power of the representational tool hindered students in establishing and maintaining shared understanding of the domain (Suthers et al., 2003; Van Boxtel & Veerman, 2001). In other words, when students are unable to specify (i.e., conceptual tool) or being forced to explicitly specify (i.e., simulation tool) the relationship between concepts this hinders students in properly referring to and relating their contributions in CSCL-environments.

Although the results indicate that scripting student tool use seems beneficial for problem-solving and learning, there were some contrasting findings that require further discussion. First, student interaction and complex learning-task performance in the match condition was very similar to that in the causal condition. Since students in both conditions received the causal representational tool they were both facilitated in constructing and discussing a causal domain representation. Supporting students' causal reasoning seems, thus, important for learning (Jonassen & Ionas, 2008; McCrudden et al., 2007). This result raises questions about whether constructing and applying multiple representations of a domain is beneficial for complex learning-task performance. When students regard a specific representation as beneficial for learning and/or encounter difficulties in combining multiple representations, they might choose to stick with a more familiar one and make no attempt to combine them (Ainsworth, 2006; Bodemer & Faust, 2006). Second, students in the causal condition represented more concepts and relationships in comparison to students in the other conditions. This evoked more elaborate discussions of the domain which could have supported them in carrying out their complex learning-task. It is, however, noteworthy that the relationships that they represented were more often incorrect in comparison to the conceptual and the simulation conditions. The construction and discussion of representations might, thus, be more important for complex learning-task performance than the correctness of the representations (Brna et al, 2001; Cox, 1999). It might also be that permitting students to make errors during their complex learning-task performance may provide opportunities for learning. In this way, construction of incorrect representations can be regarded as a productive exercise in failure (Kapur, 2008).

5. Implications and future research

The obtained results mainly confirmed our expectations and are in line with those of others who stress the importance of sequencing and interrelating multiple (i.e., qualitative and quantitative) representations of the knowledge domain during the collaborative performance of a complex learning-task (Ertl et al., 2008; Jonassen, 2003; Ploetzner et al., 1999; Frederiksen & White, 2002). These results also have several implications for designing learning-environments (e.g., CSCL-environments) aimed at fostering students' complex learning-task performance. Combining the advantages of scripting and using multiple presentational tools facilitates students in constructing and discussing different representations of the domain. When properly matched to the part-task demands, the complementary function of those representations can evoke elaborated and meaningful discussion of the domain and foster students' complex learning-task performance (e.g., Ainsworth, 2006). To our knowledge, such an approach has not been used in other studies. Ertl et al., for example, used a condition in which scripting was employed to structure the problem-solving process and a specific representation was applied. Their design, however, did not allow them to compare the effects found with those of conditions in which scripting and student use of multiple representational tools were combined. However, when interpreting the results and the implications of this study one has to take into consideration that there were contrasting findings that require additional research to investigate:

- whether students indeed require qualitative as well as quantitative representations during their collaborative performance of complex learning-tasks,
- whether students combine qualitative and quantitative representations during their collaborative performance of complex learning-tasks, and

- how constructing different representations affects the quality (i.e., correctness) of students' discussions of the domain.

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Table 1

Congruence between Representational Tool and Phase-related Part-task Demands

Problem phase	Task demand	Representational tool	Representational guidance
Problem orientation	Determining core concepts and relating them to the problem	Conceptual	Representing concepts and their conceptual relationships
Problem solution	Proposing multiple solutions to the problem	Causal	Representing causal relationships between the concepts and the possible solutions
Solution evaluation	Determining suitability of the solutions and coming to a final solution to the problem	Simulation	Representing mathematical relationships between the concepts and enabling manipulation of their values

Table 2

Overview of the Experimental Conditions

Condition	Problem phases and provided representational tool			Match/mismatch
	Problem orientation	Problem solution	Solution evaluation	
Conceptual	*Conceptual tool*	Conceptual tool	Conceptual tool	Match for the orientation phase only
Causal	Causal tool	*Causal tool*	Causal tool	Match for the solution phase only
Simulation	Simulation tool	Simulation tool	*Simulation tool*	Match for the evaluation phase only
Match	*Conceptual tool*	*Causal tool*	*Simulation tool*	Match for all problem phases

Table 3

Coding and Category Kappa's (K_c) of Students' Meta-cognitive, Cognitive and Off-task Activities

Activities	Discourse topic	Discussion of	K_c
Meta-cognitive			.69
	Planning	the problem-solving strategy; how and when the group has to carry out a specific activity	.58
	Monitoring	whether they have finished the part-tasks on time	.56
	Evaluating	the suitability of their problem-solving strategy	.64
Cognitive			.65
	Preparation	the goal of the problem-solving task and the different part-tasks	.45
	Executing	content-related topics and formulating/revising their decisions to the part-tasks	.70
	Ending	how, where, and when their decisions need to be registered	.51
Off-task			.76
	Social	non-task related topics	.80
	Technical	problems with the CSCL-environment	.60

Table 4

Coding and Category Kappa's (K_c) MEPA-filter of Students' Discussion of the Domain

Categories	Discussion of the	K_c
Concepts	business-economics concepts	.83
Solutions	possible interventions	.75
Relations	different kinds of interrelationships	.68

Conceptual	definition/meaning of a concept/solution	.69
Causal	causal relationship within/between concepts/solutions	.73
Mathematical	quantitative relationships within/between concepts	.62

Table 5

Coding of Students' Communicative Activities

Activities	Dialogue Act	Description	Example discourse marker
Focusing	Elicitative proposal for action	Proposition for action	Let's start with the first part-task?
	Elicitative question open	Open question with a lot of alternatives	Shall we fist look at the description of the assignment or at the description of the part-tasks?
	Imperative action	Command to perform an action	Finish the decision to the second part-task
	Imperative focus	Command for attention	Look at the representational tool!
	Elicitative question verify	Question that can only be answered with yes or no	Do you refer to the company result??
Checking	Elicitative question set	Question where the alternatives are already given (set)	Are you for or against increasing sales?
	Responsive confirm	Confirming answer	Yes, we indeed should start a promotion-campaign
	Responsive deny	Denying answer	No, that is not a good solution
	Responsive accept	Accepting answer	Oh, Yes that OK
Argumentation	Argumentative reason	Reason	Because this solution does not affect our costs
	Argumentative against	Objection	But this would cost more money
	Argumentative conditional	Condition	If we increase the selling price…
	Argumentative then	Consequence	Then the cost price decreases
	Argumentative disjunctive	Disjunctive	We can increase the actual sales through a promotion-campaign or by decreasing the selling price or by ….
	Argumentative conclusion	Conclusion	Thus we can conclude that the third solution leads to the best company result.

Table 6

Items and Reliability of Complex Learning-task Performance

Criteria	Description	Items	α
Suitability	Whether the groups' decisions were suited to the different part-tasks	9	.81
Elaboration	Number of different business-economics concepts or financial consequences incorporated in the decisions to the different part-tasks	9	.56
Justification	Whether the groups justified their decisions to the different part-tasks	9	.71
Correctness	Whether the groups used the business-economics concepts and their interrelationships correctly in their decisions to the different part-tasks	9	.68
Continuity	Whether the groups made proper use of the decisions from a prior problem phase	2	.67
Quality advice	Whether the groups gave a proper final advice - Number of business-economics concepts incorporated in the advice - Number of financial consequences incorporated in the advice - Whether the final advice conformed to the guidelines provided	3	.76
Total score	Overall score on the complex learning-task performance	41	.92

Table 7

Multilevel Analyses for Effects of Match Condition versus Non-matched Conditions concerning Students' Meta-cognitive, Cognitive and Off-task Activities

	Conceptual condition ($n_{student}$ = 24)	Causal condition ($n_{student}$ = 24)	Simulation condition ($n_{student}$ = 24)	Match condition ($n_{student}$ = 21)	Effects match condition ($N_{student}$ = 93)		
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	$\chi^2(3)$	β	*SE*
*Meta-cognitive**	23.54 (9.12)	30.32 (18.80)	17.65 (12.38) -	26.91 (13.20) +	17.15	1.74	2.66
Planning	4.54 (3.02)	6.59 (5.80)	2.96 (2.42)	5.32 (4.69)	9.03	0.73	0.77
Monitoring*	13.33 (5.79)	16.95 (11.17)	10.43 (6.81) -	15.27 (7.17) +	13.05	1.00	1.40
Evaluating	5.67 (2.35)	6.77 (4.41)	4.26 (4.45)	6.32 (4.29)	6.56	0.35	0.76
*Cognitive**	20.71 (11.08)	23.68 (17.81)	15.57 (11.11) -	25.73 (11.94) +	15.27	2.64	3.03
Preparation*	2.83 (2.60)	4.23 (3.49)	1.83 (2.10) -	3.32 (1.94) +	7.39	0.25	0.46
Executing*	14.54 (8.56)	15.68 (11.79)	11.26 (8.56) -	18.59 (10.03) +	12.88	2.09	2.24
Ending	3.33 (2.78)	3.77 (4.06)	2.48 (2.02)	3.82 (2.84)	3.71	0.28	0.63
Off-task	9.96 (10.14)	9.82 (7.42)	5.78 (3.53)	9.41 (8.48)	10.19	-0.30	1.55
Social	8.50 (9.89)	7.86 (6.47)	4.22 (3.34)	6.64 (7.27)	9.09	-0.74	1.44
Technical	1.46 (1.38)	1.95 (1.79)	1.57 (1.59)	2.27 (2.29)	0.23	0.43	0.33

Notes. * $p < .05$; if match condition significantly > a mismatch condition than the match condition is indicated with a + and the mismatch condition with a -

Table 8

Multilevel Analyses for Effects of Match Condition versus Non-matched Conditions concerning Students' Discussion of the Domain

	Conceptual condition ($n_{student} = 24$)	Causal condition ($n_{student} = 24$)	Simulation condition ($n_{student} = 24$)	Match condition ($n_{student} = 21$)	Effects match condition ($N_{student} = 93$)		
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	$\chi^2(3)$	β	*SE*
Concepts	21.17 (15.28)	26.27 (20.66)	17.22 (13.92)	26.09 (14.76)	14.90	2.41	3.45
Solutions	20.62 (23.12)	29.86 (31.24)	21.27 (27.24)	16.36 (13.26)	14.70	1.27	3.59
Relations[*]	29.17 (16.21)	35.73 (29.01)	21.30 (17.00) -	32.82 (15.66) +	17.41	1.73	4.22
Conceptual	9.29 (4.97)	11.27 (9.88)	6.04 (4.94)	9.14 (5.41)	11.20	-0.04	1.33
Causal	15.38 (10.35)	19.59 (17.76)	10.96 (1.16)	18.91 (10.28)	14.43	0.59	2.62
Mathematical[*]	4.50 (5.06)	4.86 (3.69)	4.30 (5.04) -	4.77 (3.53) +	3.90	0.17	0.84

Notes. [*] $p < .05$; if match condition significantly > a mismatch condition than the match condition is indicated with a + and the mismatch condition with a -

Table 9

Multilevel Analyses for Effects of Match Condition versus Non-matched Conditions concerning Students' Communicative Activities

	Conceptual condition ($n_{student}$ = 24)	Causal condition ($n_{student}$ = 24)	Simulation condition ($n_{student}$ = 24)	Match condition ($n_{student}$ = 21)	Effects match condition ($N_{student}$ = 93)		
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	$\chi^2(3)$	β	*SE*
*Coordination**	124.33 (59.01)	173.82 (130.42)	87.65 (54.21) -	170.36 (79.22) +	30.06	24.02	19.40
Focusing*	22.87 (8.20) -	31.50 (23.37)	18.13 (12.28) -	31.09 (15.83) +	18.42	4.30	3.52
Checking*	57.33 (31.43) -	88.95 (69.43)	39.17 (26.471) -	84.14 (38.56) +	27.74	14.22	9.84
Argumentation*	44.12 (26.92)	53.36 (43.65)	30.35 (19.95) -	55.14 (32.18) +	20.90	5.41	6.61

Notes. * $p < .05$; if match condition significantly > a mismatch condition than the match condition is indicated with a + and the mismatch condition with a -

Table 10

One-way Multivariate Analysis of Variance for Effects of Match Condition versus Non-matched Conditions concerning Complex Learning-task Performance

Criteria	Conceptual condition ($n_{group} = 8$)	Causal condition ($n_{group} = 8$)	Simulation condition ($n_{group} = 8$)	Match condition ($n_{group} = 7$)
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
Suitability	14.38 (2.13)	15.38 (0.74)	13.75 (1.70)	15.57 (2.15)
Elaboration	11.62 (2.13)	13.50 (2.93)	11.75 (2.66)	13.71 (2.29)
Justification*	4.62 (2.20) -	7.50 (2.67)	4.62 (1.51) -	7.57 (1.90) +
Correctness*	7.12 (1.55) -	9.25 (2.49)	8.12 (1.36) -	9.86 (0.69) +
Continuity	3.50 (0.76)	3.75 (0.46)	3.00 (0.93)	3.29 (0.76)
Quality advice	4.00 (1.07)	5.00 (0.93)	3.88 (1.46)	4.43 (1.38)
Total score*	45.25 (7.23) -	54.38 (7.98)	45.12 (6.53) -	54.43 (6.29) +

Notes. * $p < .05$; if match condition significantly > a mismatch condition than the match condition is indicated with a + and the mismatch condition with a -

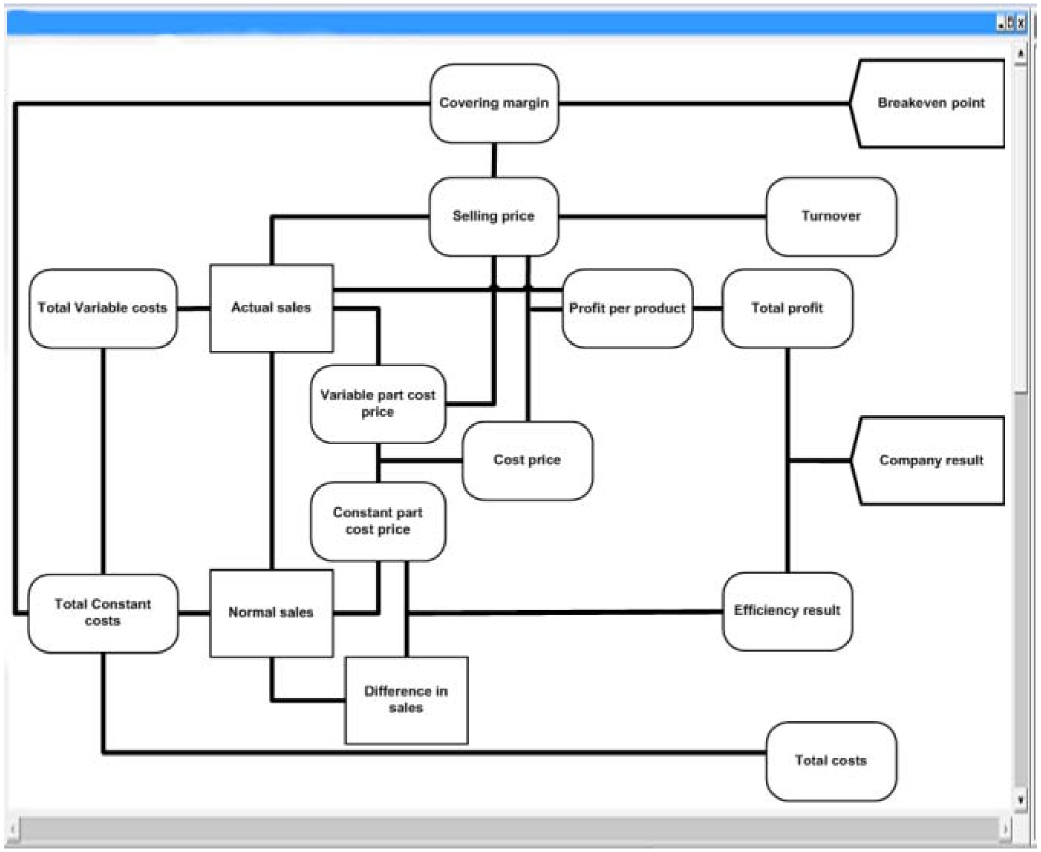

Fig 1. Conceptual representation (expert model)

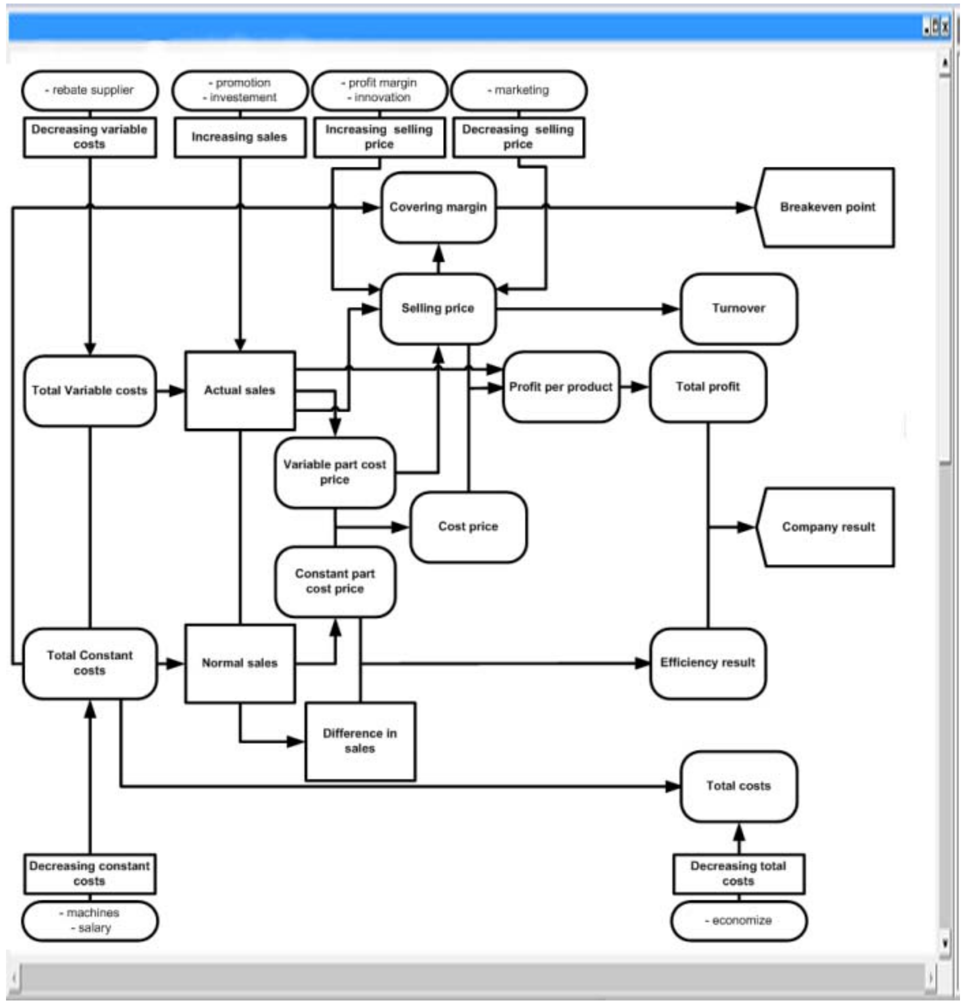

Fig 2. Causal representation (expert model)

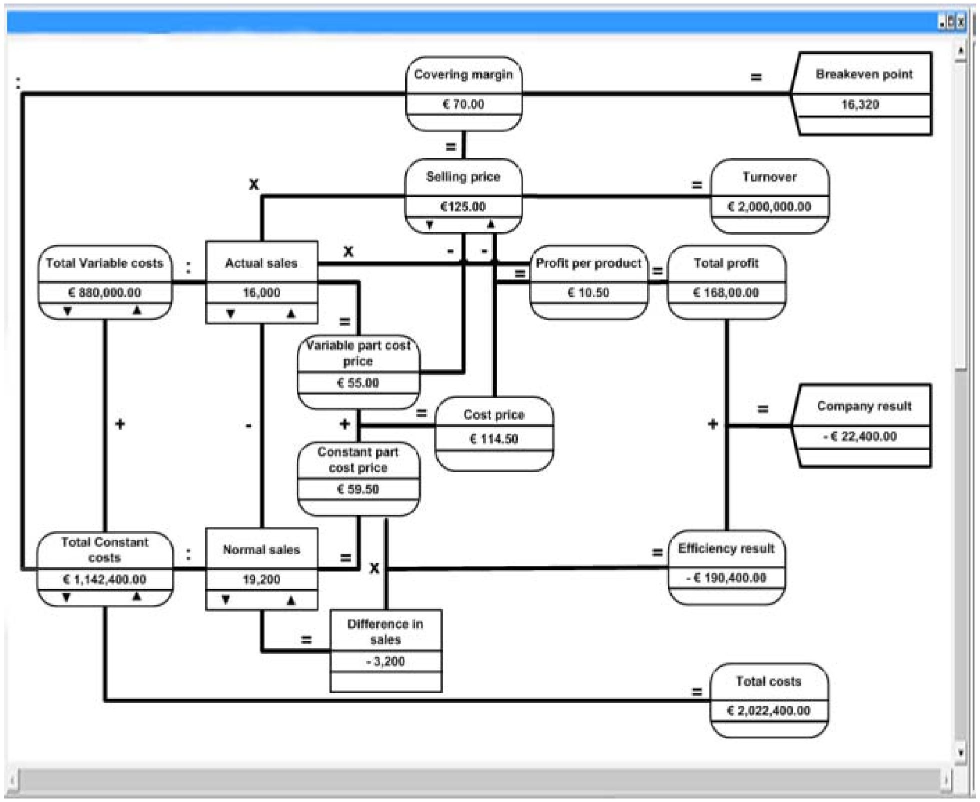

Fig 3. Simulation representation (expert model)

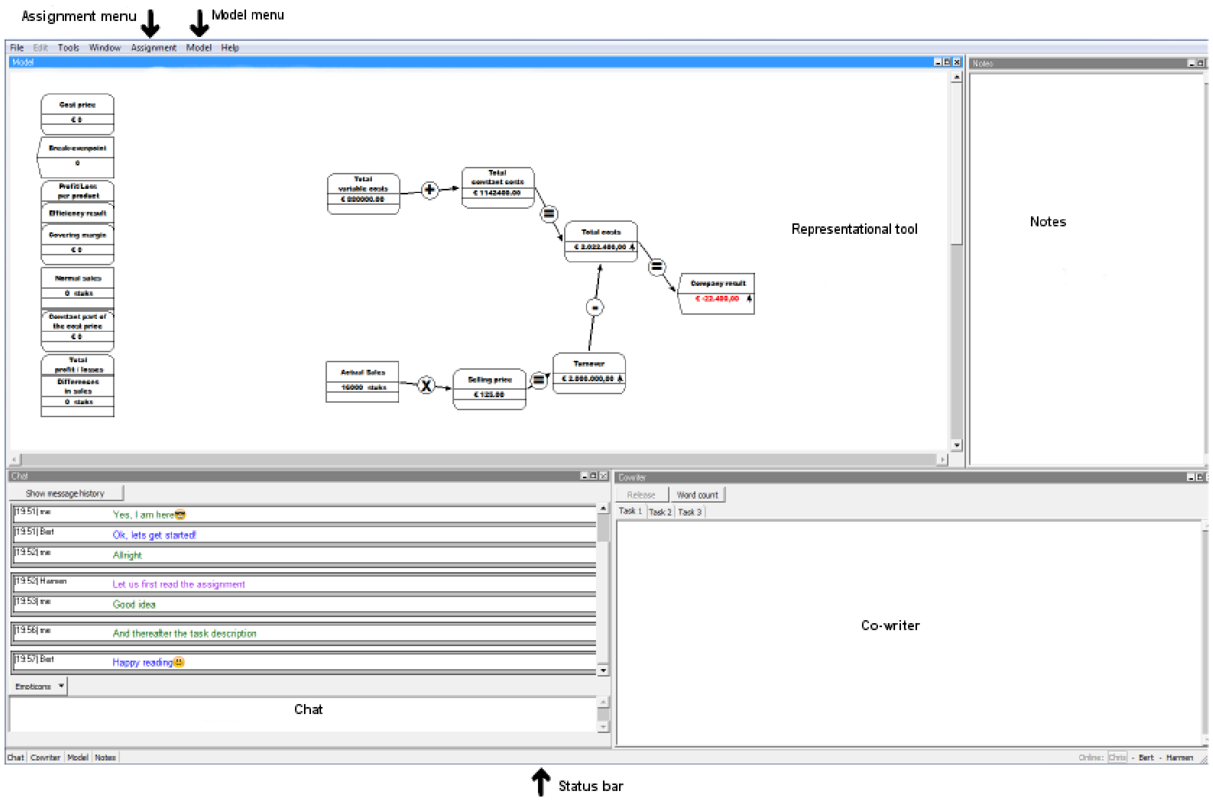

Fig 4. Screenshot of the VCRI-environment (simulation tool)

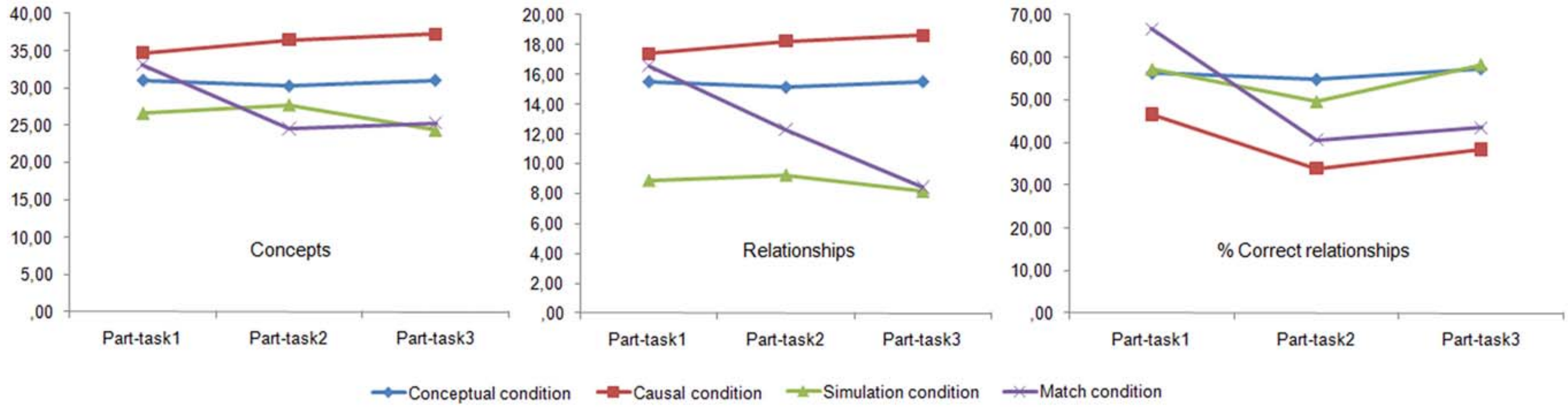

Fig 5. Content analyses for effects of match condition versus non-matched conditions concerning student tool use